V

MODELING ANALYSIS

In this Chapter we describe the air quality modeling analysis that was conducted to numerically assess the differences in onshore impacts from the various marine vessel alternatives. At the direction of the technical working group, the modeling analysis did not consider photochemistry.

A. METEOROLOGICAL MODEL

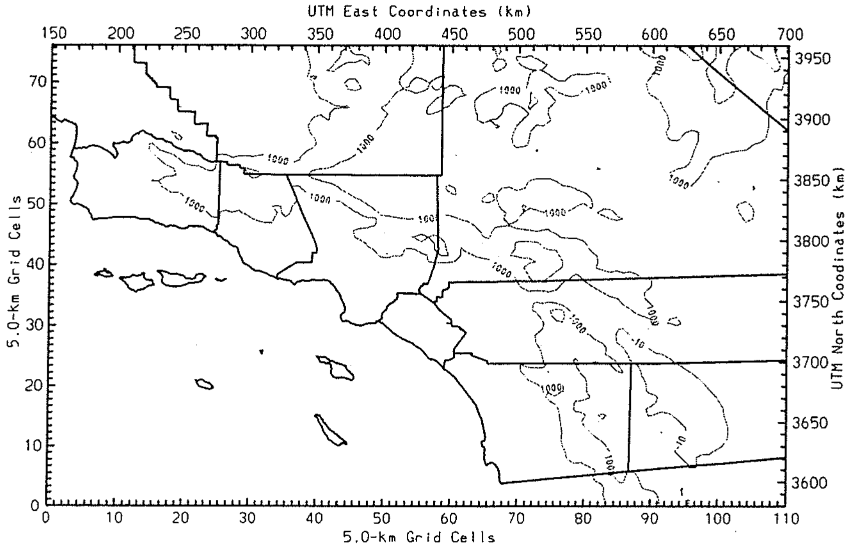
The meteorological fields were developed using CALMET, a diagnostic meteorological model (U.S. EPA, 1995). The CALMET model is based on objective analysis with diagnostic parameterizations to adjust the objective analysis results to account for non-divergence, terrain influences, and smoothing. It is limited in that the resulting parameter fields are only as good as the input observational data are representative, and important physical properties such as mass continuity are not ensured. However, CALMET is relatively easy to run and to manipulate its output to ensure idealized flow patterns. Care was taken to ensure that the model was exercised in a manner that would be appropriate for the region on any day, and not just the day of the tracer release.

The modeling domain was defined in a UTM coordinate system with 110 x 74 grid cells with a resolution of 5-km (Figure V-1). The domain coordinate system was defined as follows:

UTM Zone 11:	Easting:	150.0–700.0 km
	Northing:	3580.0–3950.0 km

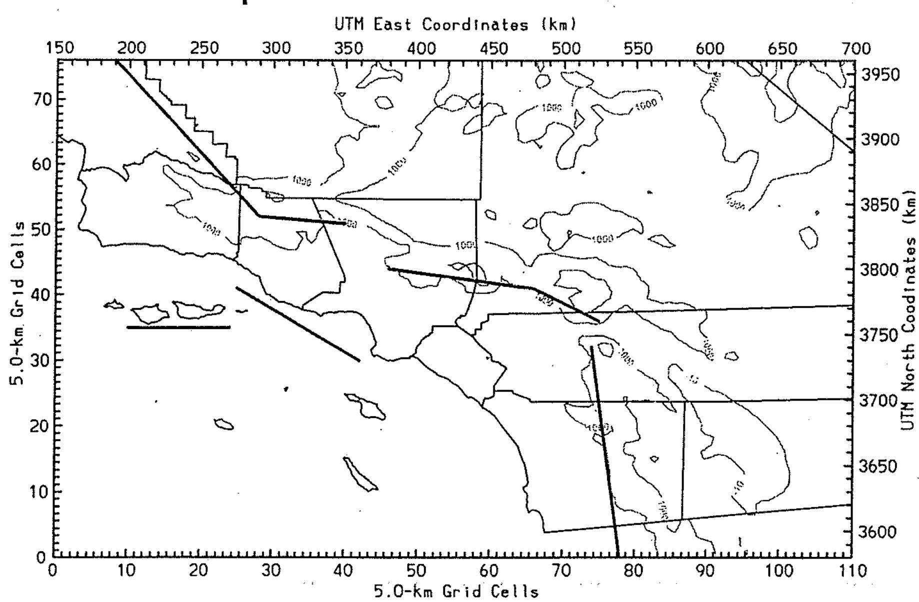
The vertical CALMET domain was defined using 16 layers to a height of 5000 meters above ground level.

Figure V-1
Air Quality Modeling Domain



Interpolation barriers were defined to limit offshore extrapolation from onshore wind monitoring sites, and to limit extrapolation from either side of the crests of various mountain ranges (see Figure V-2). Meteorological data collected during the SCOS97 were input to the model and used to generate three-dimensional meteorological fields for September 4-5, 1997.

Figure V-2
Interpolation Barriers Used in CALMET



B. WINDFIELD VALIDATION AND PEER REVIEW

In order to provide the best possible windfields for the simulated comparative analyses, a windfield validation component was included as an integral part of the windfield development process. In addition, peer review was provided by a group of meteorologists and air quality modelers with expertise in the southern California region. Participants in the peer review process included the U.S. Navy, Ventura County APCD, San Diego County APCD, Santa Barbara County APCD, South Coast AQMD, and the ARB. The group reviewed interim products and provided valuable suggestions for windfield improvement. Due to the compressed time frame for completing the technical work and unforeseen resources required to complete the tracer data analysis, the peer review group was not able to complete their peer review of the September 4-5 windfields. They did, however, reach consensus on the acceptability of windfields for August 3-7, a SCOS97 episode that is also available for simulating the onshore impacts of the marine vessel control strategy options.

In the remainder of this section we summarize the simulation of the September 4-5, 1997 tracer experiment using the CALGRID air quality model (Sigma Research Corp. 1989). The simulation results were compared with tracer concentrations observed onshore in southern California to validate the use of the air quality model for assessing the impact of offshore emissions. Subsequent to successful model validation, the model was applied to two episode periods to assess the relative impacts of shipping emissions from several shipping scenarios on southern California.

<u>Tracer Emission Inventory</u>

In this experiment, the tracers were released from moving and stationary point sources resolved to the minimum grid resolution for the model, which was 5 km. These emissions were constant for each 1-hour period.

To develop the tracer emission inventory for the air quality model, the position of each ship was calculated at 1-km intervals along the tracer release path. The time required for each 1-km traverse was calculated and the tracer released during that time period was also calculated, based on the average change in weight in the tracer canisters for that period. At each 1-km interval, the position of each ship was translated into the grid cell coordinate of the air quality modeling domain and the emissions were added to that grid cell in the gridded emission inventory. Because the emissions were prorated in each grid cell based on 1-km traverse intervals, and because each release path could not be exactly represented in 1-km increments, the mass of the simulated tracer emissions were close to, but did not exactly match the actual mass of tracer emissions (Table V-1).

Table V-1
Simulated and Measured Tracer Release Data for the September 4, 1997 Tracer Experiment

Shipping Lane	Release Type	Tracer	Measured Release Mass (g)	CALGRID Emitted Mass (g)
Both *(point of separation)*	Stationary	PDCB	940	935
Current *(morning, near shore)*	Moving	PDCH	3470	3500
Proposed *(morning, near shore)*	Moving	PTCH	2800	2766
Current *(afternoon, offshore)*	Moving	PMCH	2350	2354
Proposed *(afternoon, offshore)*	Moving	PMCP	2990	3000

Simulations

The CALMET meteorological fields and the emission inventory prepared from the September 4, 1997 tracer experiment were used as inputs to the CALGRID air quality model. The CALGRID domain was identical to the CALMET domain (110x74x16 cells). Since the tracer chemical species are inert, the model was run with photochemistry disabled. The CALGRID model was run for the period September 4, 0200 PDT to September 5, 2300 PDT and generated 3-dimensional, hourly concentrations of each tracer.

As a check on the integrity of the simulation results, the total mass of each tracer within the modeling domain was calculated hourly, as well as the total mass over water and the total mass over land. These results show that after 24 hours from the end of the tracer release periods, at least 90% of the mass of each tracer is still within the modeling domain (Figures V-3 through V-7). The decline in total mass after 24 hours was attributed to mass leaving the modeling domain at the domain boundaries.

Figure V-3
Total, Overwater, and Overland Mass of PDCB in the CALGRID Modeling Domain
(PDCB released from point of separation in the morning)

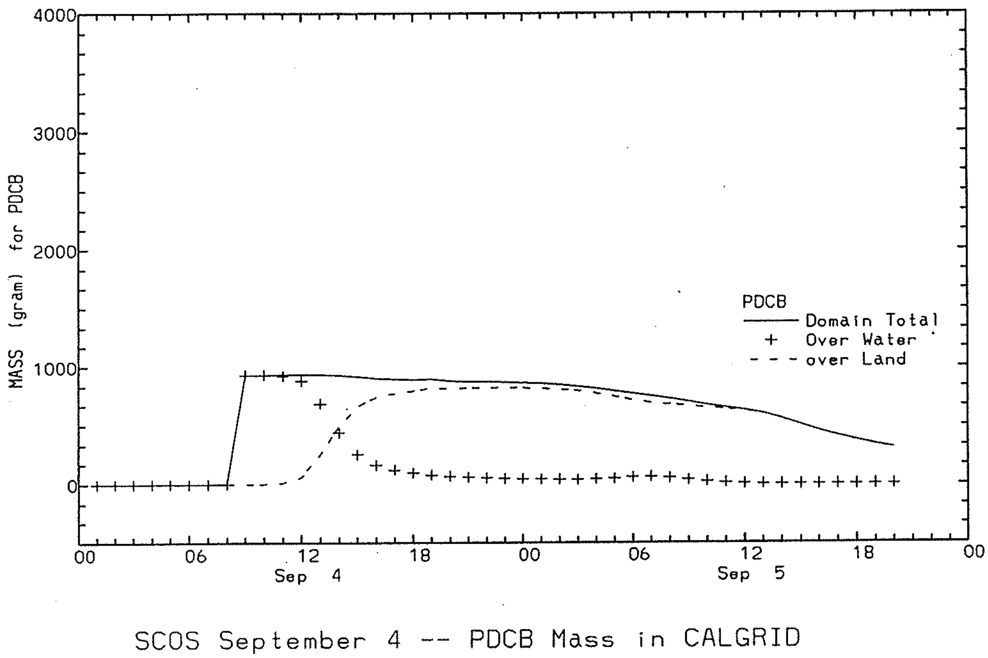


Figure V-4
Total, Overwater, and Overland Mass of PDCH in the CALGRID Modeling Domain
(PDCH released from current shipping lane in the morning)

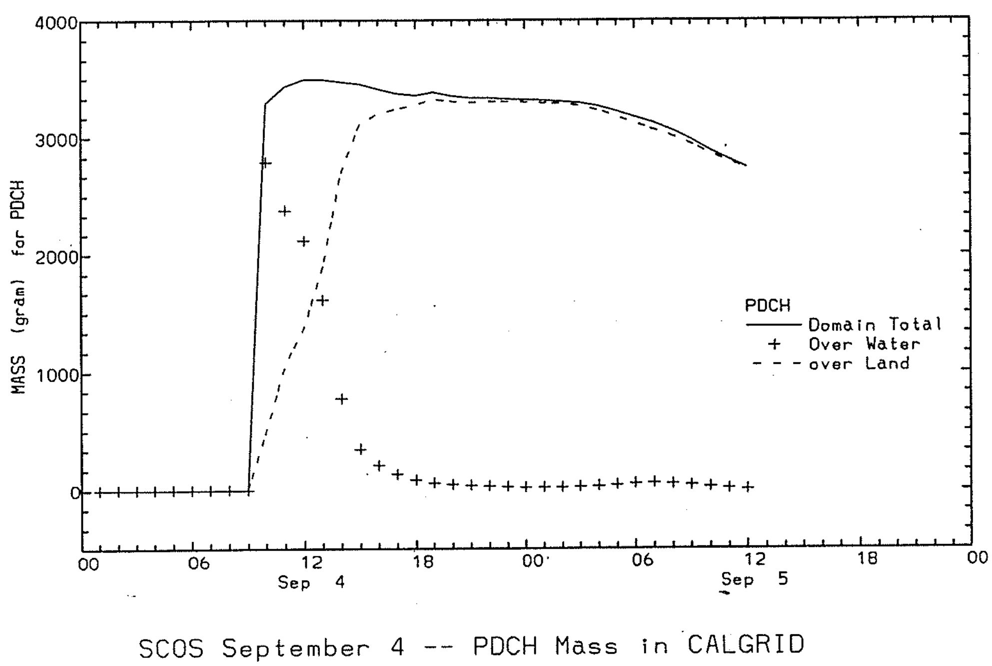
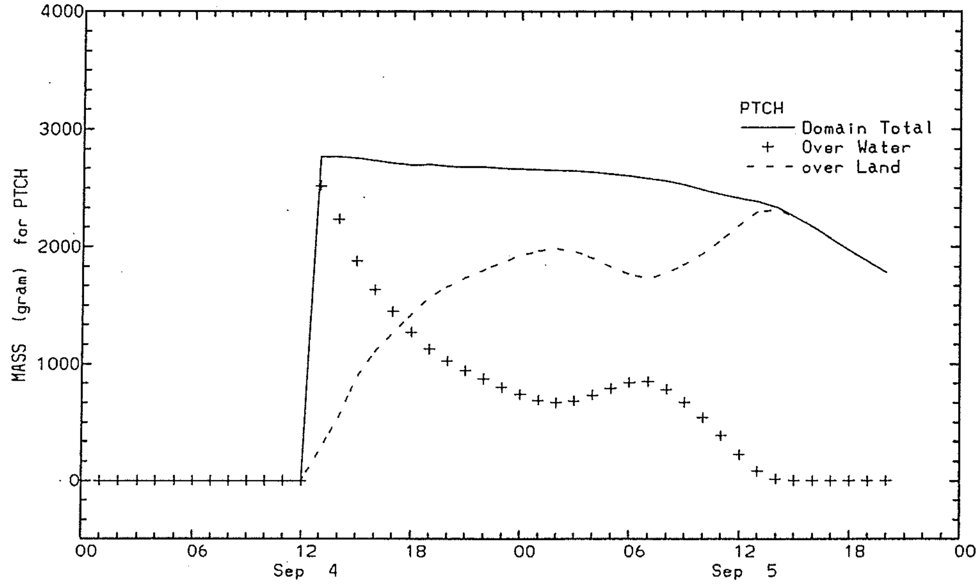
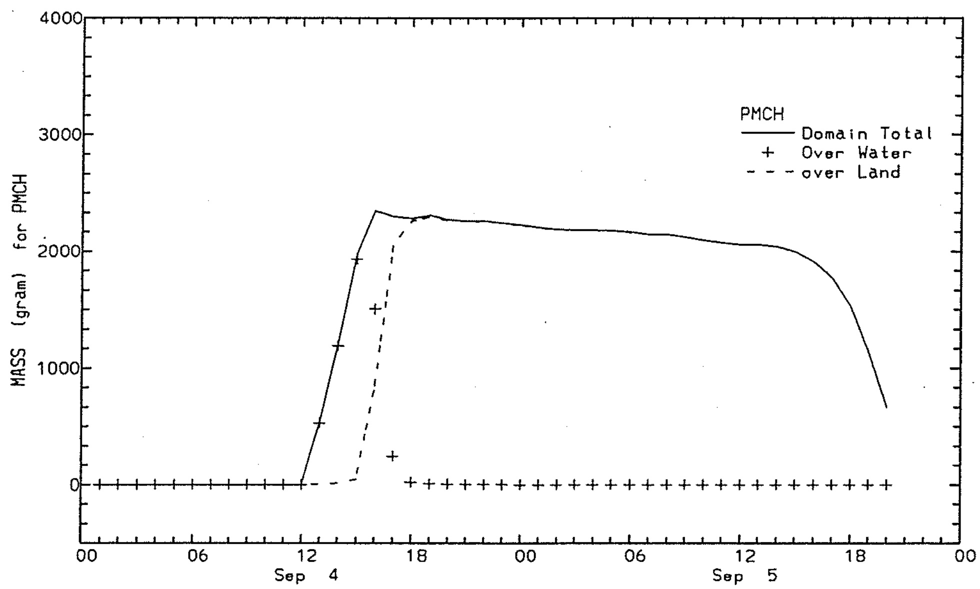


Figure V-5
Total, Overwater, and Overland Mass of PTCH in the CALGRID Modeling Domain
(PTCH released from proposed shipping lane in the morning)



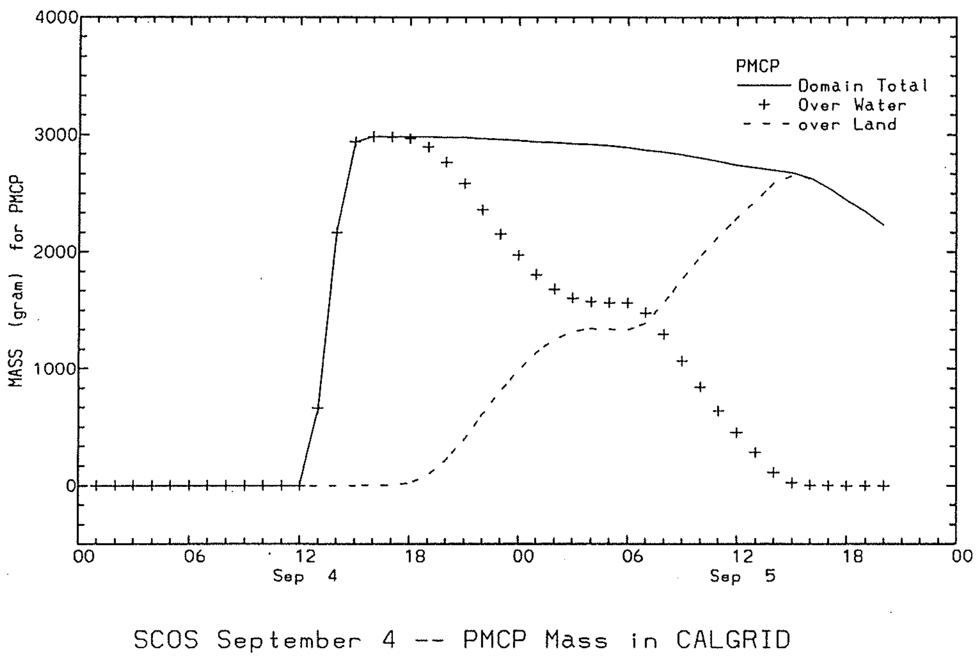
SCOS September 4 -- PTCH Mass in CALGRID

Figure V-6
Total, Overwater, and Overland Mass of PMCH in the CALGRID Modeling Domain.
(PMCH released from current shipping lane in the early afternoon)



SCOS September 4 -- PMCH Mass in CALGRID

Figure V-7
Total, Overwater, and Overland Mass of PMCP in the CALGRID Modeling Domain.
(PMCP released from proposed shipping lane in the early afternoon)



Windfield Validation

Windfield validation is actually a validation of the modeling system, which includes as components a meteorological model, an emissions model, and an air quality model. The objective of this validation analysis was to compare the results from the tracer experiment with the results from the simulated tracer experiment to ensure that the modeling system adequately represented the tracer experiment and, by inference, the behavior of air pollutants within the modeling domain.

One direct measure of the impact of offshore emissions on onshore air quality is the accumulated mass flux and its distribution along the shoreline of southern California resulting from the offshore emissions. Mass flux calculations can be made from the simulation results. However, mass flux calculations from the observational data are more problematic. The observations are ground level only, and the vertical extent of the observed concentrations is unknown. Also, there were large areas of the study domain, including those portions over water and those in the inland deserts, in which there were limited or no tracer concentration measurements. Thus, to estimate the impact of offshore emissions from the observational data requires relative, rather than absolute comparisons.

- ***Mass Fluxes from Simulation Results***

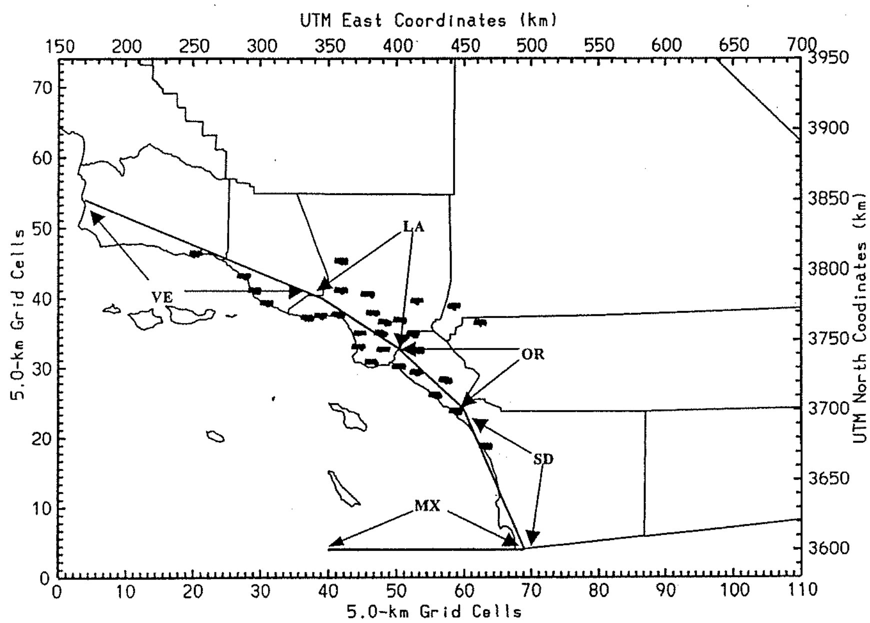
To calculate onshore mass fluxes from the offshore tracer releases, a series of line segments were defined for Ventura County (VE), Los Angeles County (LA), Orange County (OR), San Diego County (SD), and the southern boundary of the California Bight (MX) (see Figure V-8). By post-processing the CALGRID simulation results, the hourly mass flux across each of these line segments was calculated from the surface to a height of 2000 meters above ground level, using the following relationship:

$$
\begin{aligned}
FLUX = {} & (WSPD) * \cos(WDIR - ANGLE) \\
& * CONC * WMOL * SAREA * MDEN
\end{aligned}
$$

where	FLUX	=	mass flux (gm/hour),
	WSPD	=	wind speed (m/sec),
	WDIR	=	wind direction,
	CONC	=	tracer concentration (volume %)
	ANGLE	=	the orientation angle for each line segment,
	WMOL	=	tracer molecular weight (gm/gm-mole),
	SAREA	=	cross-sectional area of each grid cell (m^2), and
	MDEN	=	molecular density (gm-mole/m^3) corrected to ambient temperature and pressure.

This mass flux calculation was only an approximation of the actual mass fluxes calculated within the CALGRID model. Within the model, mass fluxes are calculated at intervals of between 5 and 10 minutes using equations that are non-linear and concentration gradients interpolated over a number of grid cells. However, the tracer concentrations output by the model at 1-hour intervals represent only the most recent time step. The average hourly concentrations can only be estimated. Also, the above flux calculation accounts for advective fluxes only. Diffusive fluxes within the model may also have been important in the determination of mass distribution, especially where concentration gradients were large and wind speeds were low.

Figure V-8
Line Segments Used to Calculate Mass Flux for Ventura (VE), Los Angeles (LA), Orange (OR), and San Diego (SD) Counties, and the Southern End of the California Bight (MX) (Markers denote tracer sampling sites.)



The simulated, hourly net mass fluxes across the vertical planes represented by each of the line segments were accumulated for the period September 4, 0200 PDT through September 5, 2300 PDT. The results of these calculations (Tables V-2 and V-3) show that simulated flows advected through all line segments accounted for between 90% (PMCP) and 107% (PMCH) of the mass from the tracer releases. Only small mass fractions of any of the tracers passed through the line segments represented by Ventura County or the California Bight.

The 107% mass of PMCH accounts for slightly more mass than was released during the tracer experiment. Also, the 90% of the PMCP mass in the flow calculations suggests that not all of the PMCP mass was accounted for by the model. Eulerian models have been known to create or remove mass because of characteristics of the numerical methods used. However, mass calculations for the domain (see Figures V-3 through V-7) show that 95% or more of the mass of each tracer was conserved within the modeling domain well after the release period, and until the tracers reached the domain boundaries. Therefore, these apparent discrepancies in the accumulated mass fluxes were attributed to the approximate nature of the mass flow calculations. Because most (90% to 107%) of the mass was accounted for in the calculations, and since the total mass within the modeling domain was largely conserved, it was concluded that the simulated relative distribution of mass flux for each tracer was a reasonable approximation of the observed distribution.

Table V-2
Distribution of Simulated, Accumulated Net Tracer Mass Fluxes (grams) Among the Defined Line Segments
(Numbers in parentheses represent percentage of total)

Shipping Lane	Tracer	VE	LA	OR	SD	MX	Total
Both *(point of separation)*	PDCB	4 (0%)	8 (1%)	745 (81%)	137 (15%)	21 (2%)	915
Current *(morning, near shore)*	PDCH	0 (0%)	308 (9%)	2949 (89%)	60 (2%)	1 (0%)	3318
Proposed *(morning, near shore)*	PTCH	13 (0%)	181 (7%)	2159 (79%)	333 (12%)	63 (2%)	2749
Current *(afternoon, offshore)*	PMCH	16 (1%)	2102 (84%)	391 (16%)	0 (0%)	0 (0%)	2509
Proposed *(afternoon, offshore)*	PMCP	64 (2%)	1054 (39%)	1351 (50%)	199 (7%)	32 (1%)	2700

Table V-3
Percentage of Emitted Tracer Mass Accounted for by Mass Fluxes Through Onshore Line Segments Calculated from Simulation Results

Shipping Lane	Tracer	Simulated Mass (g)	Released Mass (g)	Fraction (%)
Both *(point of separation)*	PDCB	915	940	98
Current *(morning, near shore)*	PDCH	3318	3470	96
Proposed *(morning, near shore)*	PTCH	2749	2800	99
Current *(afternoon, offshore)*	PMCH	2509	2350	107
Proposed *(afternoon, offshore)*	PMCP	2700	2990	90

- ***Mass Fluxes from Observations***

The calculation of mass fluxes from observations at surface monitoring sites required a number of assumptions. The horizontal and spatial representativeness of the concentrations observed at each site was unknown. Also, horizontal gradients can only be inferred from concentrations at surrounding sites based on the assumption that the spatial resolution of the monitoring network is smaller than the spatial scale of the cross section of the plume being sampled. The current and proposed offshore shipping lane release points were on a scale of 100 km upwind of Orange County where the highest concentrations of the tracers released were observed. Based on Pasquill's diffusion curves for neutral conditions, at 100 km distance, the cross-sectional width of a point source plume would be approximately 10 km (USAEC,1968). The near shore (morning) tracer releases were even closer to the shoreline, with correspondingly narrower plumes. Therefore, there is uncertainty associated with estimating mass fluxes based on the tracer sampling network.

For this analysis, the horizontal distribution of each tracer concentration was determined using a distance-weighted ($1/r^2$) interpolation from the sampling sites. Each site had a maximum radius of influence of 15 km and elsewhere within the domain the concentrations were assumed to be zero. Tracer concentrations of 5 femtoliters/liter or less were assumed to be zero (to account for background). Such an interpolation would work poorly in those areas of the domain with few, or no monitoring sites; however, the concentrations were needed in this analysis only along the line segments which is where most of the monitoring sites were located. The vertical distribution of tracer concentrations was estimated by assuming constant values within the mixed layer as defined by the CALMET meteorological fields. Using these assumptions, the hourly concentration distribution of each tracer within the vertical plane defined by each line segment was calculated.

The mass flux based on the observations of each tracer, across each line segment, was calculated in the same manner as for the simulated flows. The concentrations defined for the vertical plane represented by each line segment were mapped into the CALGRID modeling domain and the CALMET wind speed and direction fields were used to calculate hourly mass flows. Accumulated mass fluxes for the period September 4, 0200 PDT through September 5, 2300 PDT were calculated (Tables V-4 and V-5). The resulting calculated mass fluxes accounted for only a small fraction of the total mass of each tracer released. The accumulated mass flows ranged between 2.0% of the released mass for PDCB to 10.3% of the released mass for PTCH.

There are many uncertainties in the assumptions on which these calculations are based and it is difficult to select just one as the cause of these low percentages. Given the spatial scale of the monitoring network and the spatial scale of the tracer plumes estimated from the Pasquill diffusion curves, actual peak tracer concentrations may have been much higher than those observed, which would have translated into much higher calculated mass flows. However, any assumption of total tracer mass distribution would necessarily be proportional to the observed concentrations. Therefore, it was concluded that the relative mass flux distribution was represented by these calculations, even though the total mass resulting from these calculations was low.

Table V-4
Distribution of Accumulated Tracer Mass Fluxes (grams) Among the Line Segments Based on Analysis of Observed Concentrations
(Numbers in parentheses represent percentage of total)

Shipping Lane	Tracer	VE	LA	OR	SD	MX	Total
Both *(point of separation)*	PDCB	0 (0%)	0 (0%)	19.1 (100%)	0 (0%)	N/A	19.1
Current *(morning, near shore)*	PDCH	0 (0%)	0 (0%)	149.0 (100%)	0 (0%)	N/A	149.0
Proposed *(morning, near shore)*	PTCH	0 (0%)	0 (0%)	249.2 (86%)	39.1 (14%)	N/A	288.3
Current *(afternoon, offshore)*	PMCH	0 (0%)	12.6 (7%)	169.8 (93)	0 (0%)	N/A	182.4
Proposed *(afternoon, offshore)*	PMCP	0 (0%)	25.8 (15%)	111.2 (64%)	36.4 (21%)	N/A	173.4

Table V-5
Percentage of Emitted Tracer Mass Accounted for by the Observed Tracer Concentrations Along Onshore Line Segments

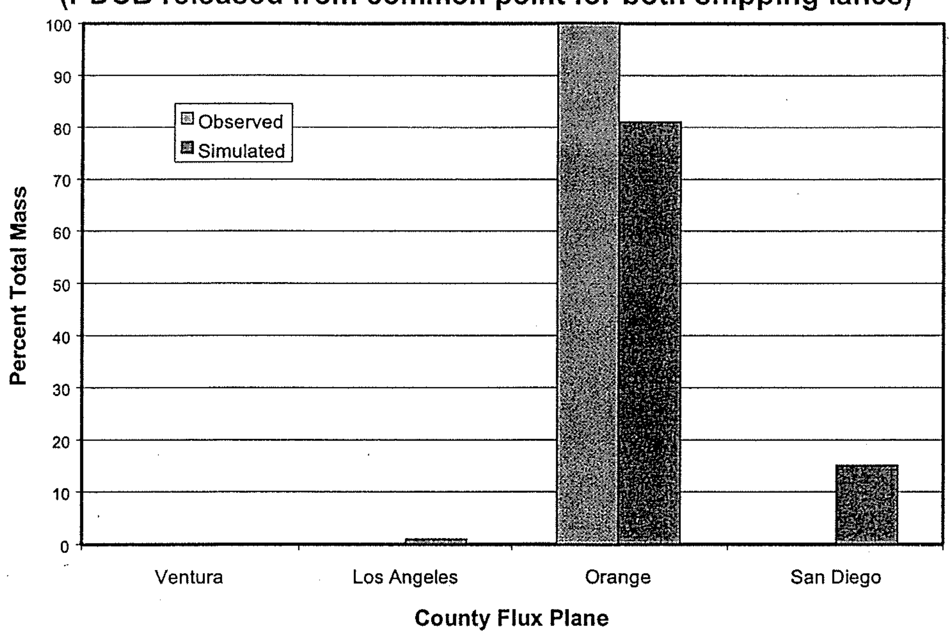
Shipping Lane	Tracer	Simulated Mass (g)	Released Mass (g)	Mass Fraction (%)
Both *(point of separation)*	PDCB	19.1	940	2.0
Current *(morning, near shore)*	PDCH	149.0	3470	4.3
Proposed *(morning, near shore)*	PTCH	288.3	2800	10.3
Current *(afternoon, offshore)*	PMCH	182.4	2350	7.8
Proposed *(afternoon, offshore)*	PMCP	173.4	2990	5.8

- ***Comparison of Simulated and Observed Mass Fluxes***

Given the low mass percentages calculated from the observed tracer concentrations, *direct* comparisons between the mass flux results from the simulations and from the observations are not appropriate. However, *relative* comparisons were made, to take advantage of the particular strength of grid-based models to estimate relative changes between strategies. Based on the CALGRID result that virtually all of the tracer mass comes onshore, it is a reasonable assumption to accept the relative distribution of tracer mass fluxes, even if the total mass cannot be accounted for in these calculations. This is because any revised estimate of mass flux would be proportional to the observed concentrations, i.e., the percentages captured would change but the relative distribution would not. Thus the relative mass fluxes can be compared to those calculated from the CALGRID simulation results.

Using the results from Tables V-2 and V-4, the percentages of the total mass flux passing through the vertical planes represented by Ventura, Los Angeles, Orange, and San Diego Counties were calculated. Comparisons between the percentages calculated from the observations and from the simulation results are shown for each tracer in Figures V-9 through V-13.

Figure V-9
Comparison of Accumulated PDCB Mass for Ventura, Los Angeles, Orange, and San Diego County Line Segments Using CALGRID Results and Tracer Measurements
(PDCB released from common point for both shipping lanes)



The tracer PDCB was released from the common, or separation, point of the current and proposed shipping lanes. Based on the observations, all of the tracer came onshore within the Orange County line segment. Based on simulation results, 81% came onshore within the Orange County line segment, and 15% came onshore within the San Diego line segment (Figure V-9).

Figure V-10
Comparison of Accumulated PDCH Mass for Ventura, Los Angeles, Orange, and San Diego County Line Segments Using CALGRID Results and Tracer Measurements
(PDCH released from current shipping lane in the morning)

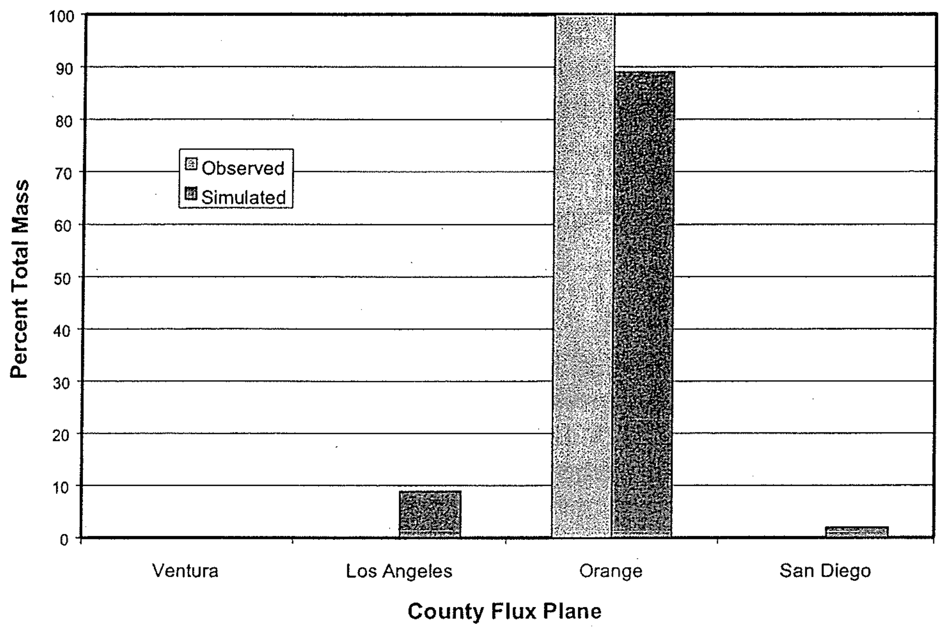
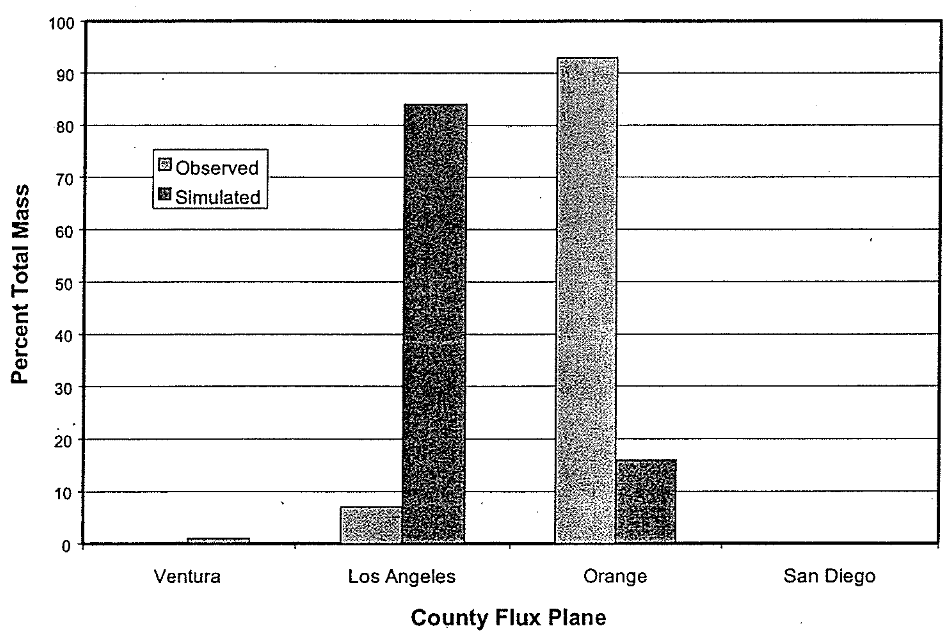


Figure V-11
Comparison of Accumulated PMCH Mass for Ventura, Los Angeles, Orange, and San Diego County Line Segments Using CALGRID Results and Tracer Measurements
(PMCH released from current shipping lane in the afternoon)



The current shipping lane was represented by two tracer releases, PDCH (morning, outbound) and PMCH (afternoon, inbound). Based on the observations, all of the PDCH tracer mass came onshore within the Orange County line segment. Based on the simulation results, 89% of the mass came onshore within the Orange County line segment, with most of the remaining 11% within in the Los Angeles County line segment (Figure V-10). For PMCH (Figure V-11), 93% of the observation-based mass came onshore within the Orange County line segment and 7% within the Los Angeles County segment, while from the simulation results only 16% came onshore within the Orange County line segment and 84% came onshore within the Los Angeles County line segment. This discrepancy is discussed further below.

Figure V-12
Comparison of Accumulated PTCH Mass for Ventura, Los Angeles, Orange, and San Diego County Line Segments Using CALGRID Results and Tracer Measurements
(PTCH released from proposed shipping lane in the morning)

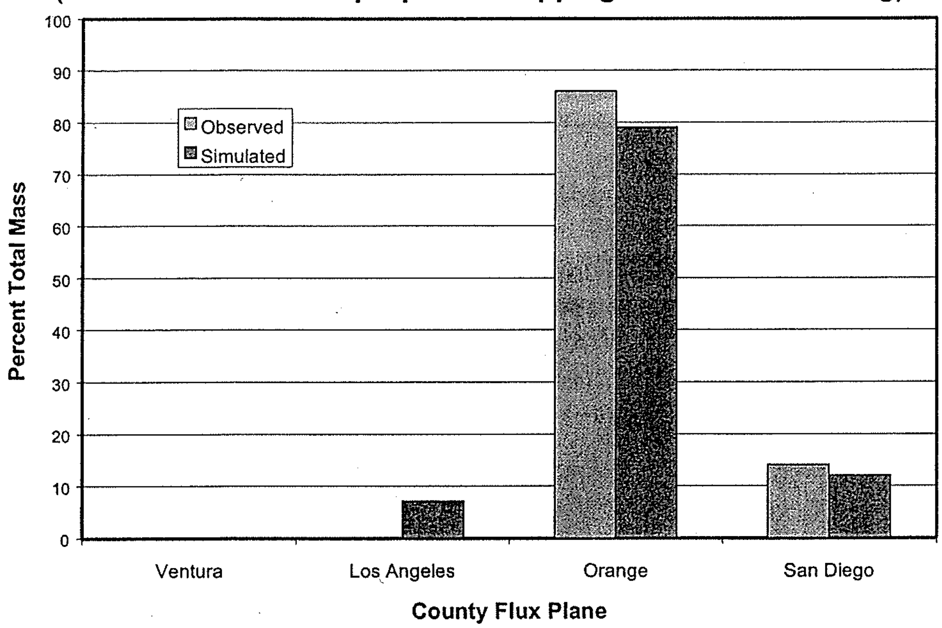
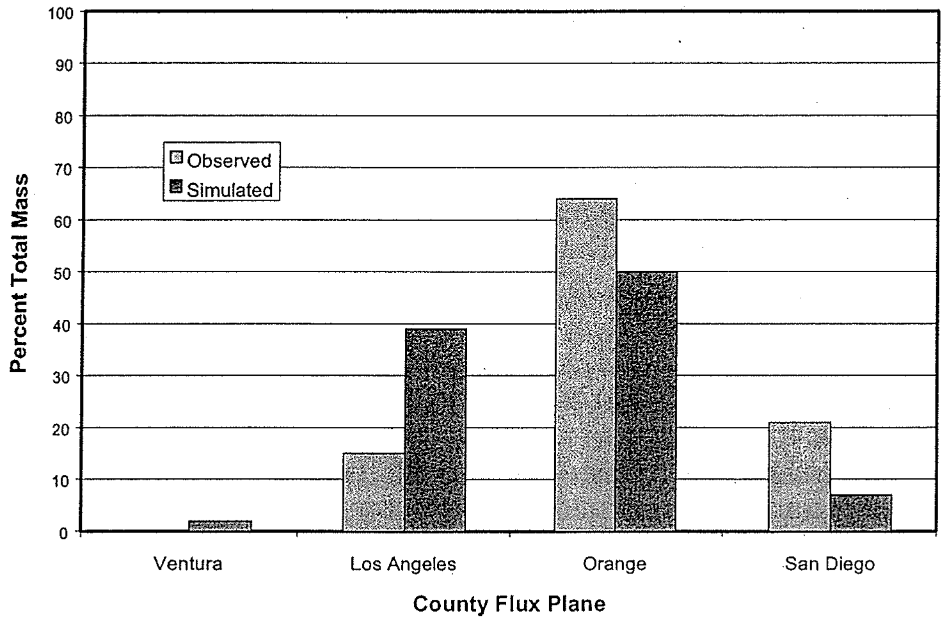


Figure V-13
Comparison of Accumulated PMCP Mass for Ventura, Los Angeles, Orange, and San Diego County Line Segments Using CALGRID Results and Tracer Measurements
(PMCP released from proposed shipping lane in the afternoon)



The proposed shipping lane was also represented by two tracers, PTCH (morning) and PMCP (afternoon). Based on the observations, 86% of the PTCH mass came onshore within the Orange County line segment, while for the simulation results 79% came onshore within the Orange County line segment (Figure V-12). For PMCP (Figure V-13), the observed onshore mass flux was distributed among the Los Angeles, Orange, and San Diego line segments, with 64% of the mass flux through the Orange County line segment and the remainder divided between the Los Angeles and San Diego County line segments. Based on the simulation results, the mass flux was also distributed among the same three line segments, with 50% of the mass flux within the Orange County line segment.

With the exception of PMCH, the relative mass flux distributions calculated from the simulation results are in general agreement with those calculated using the observations. The simulation results tend to be more widely distributed, which can be attributed to the numerical diffusion characteristic of Eulerian models. The largest discrepancy among the mass flux distributions (Figure V-11) is for PMCH, in which observations indicated that most of the mass came onshore in Orange County and the simulation results indicated a larger proportion in Los Angeles County. This discrepancy can be attributed to the wind flow patterns offshore in Santa Monica Bay. In this part of the domain, wind flow patterns are complex but are poorly represented by observations. However, both Los Angeles and Orange Counties are within the South Coast Air Basin, which is the focus of the current study. Since the onshore impact in the South Coast Air Basin is of concern, the observed and simulated mass flow distributions are in reasonable agreement.

The results from this comparison of simulated and observed mass flux distributions should be interpreted with care. In general, the simulated mass fluxes were more widely distributed than those based on observations. This was not surprising given the known tendency of Eulerian models for numerical diffusion. However, the simulation results better represent the 3-dimensions of the physical domain than do the observations. The greater distribution of the simulated tracers can be partially attributed to vertical wind shear that dispersed the tracers in a manner not detectable in ground-level observations. Also, the density of the sampling network was much less in Ventura and San Diego Counties than for Los Angeles and Orange Counties. Therefore, there was a much greater uncertainty in the mass distributions calculated from observed tracer concentrations in Ventura and San Diego Counties.

- ***Tracer Dilution Ratios (X/Q)***

The tracer dilution ratio (denoted X/Q) is a standard metric for assessing relative impacts in atmospheric tracer studies. The X/Q value is a ratio of tracer concentration within a sampling network to the tracer emission rate (units are hour/m^3). It represents a normalized index of tracer concentration to allow comparisons between different tracer experiments, release points, or different time periods during the same study.

In this analysis, peak X/Q values were calculated using the observed tracer concentrations and using the simulation results from the air quality model. The two sets of X/Q values were then compared with the objective of testing whether the pattern of X/Q values from the observations was adequately represented by those from the simulation results. The interpretation of either set of X/Q values was not an objective of this analysis. The goal was to validate the reliability of the air quality modeling system.

- ***X/Q from Observed Concentrations***

Ideally, X/Q values represent the peak plume concentrations of a tracer. In practice, however, the tracer-experiment sampling networks rarely have sufficient spatial density to measure actual peak concentrations with confidence. For example, Gaussian dispersion of the plume of a tracer released 100 km offshore could have a plume width of less than 10 km when it reached the shore (USAEC, 1968), which is approximately the width of the tracer sampling network used in the 1997 experiments. Wind speed, wind direction, the orientation of the tracer release path relative to the wind direction, and the ship movement could increase the width of the tracer plume. However, most of the tracers in this study were released much closer to the shoreline than 100 km, with plumes that were correspondingly narrower. Therefore, care must be used in interpreting X/Q values from observations.

The X/Q values were calculated using the maximum, 2-hour concentration of each tracer observed during the experimental period (most of the samplers measured concentrations averaged for 2 hours). These maximum concentrations were selected without consideration of the time or location of occurrence and are summarized in Table

V-6. Except for the PMCH tracer, the peak concentrations were measured in Orange County. The observed concentrations ranged from 9.84 to 64.45 x 10^{-9} gm/m^3.

Table V-6
Observed and Simulated Peak 2-hour Tracer Concentrations (gm/m^3 x 10^{-9}) for September 4 (County where peak occurred also shown)

Tracer	Observed		Simulated	
	Concentration	Location	Concentration	Location
PDCB	9.84	Orange	2.24	Orange
PDCH	64.45	Orange	39.70	Orange
PTCH	12.68	Orange	4.02	Orange
PMCH	13.01	Los Angeles	7.60	Los Angeles
PMCP	14.42	Orange	9.62	Orange

The tracer release periods for the September 4-5, 1997 experiment ranged from approximately 1.5 to 3 hours. The experimental plan called for the tracers to be released at a continuous rate throughout each of the release periods. In practice, however, the tracer emission rates varied markedly. Also, while the release periods varied in length, the observed tracer concentrations represented 2-hour averages. Therefore, for consistency between the tracer emissions and the observed concentrations, the emission rates used in the X/Q calculations were determined from the average emissions within the first 2 hours of each release period (see Table V-7).

Table V-7
Observed and Simulated X/Q (hour/m^3 x 10^{-12}) for September 4.*

Tracer	Emission Rate (g/hr)	Observed X/Q	Simulated X/Q
PDCB	470	20.9	4.8
PDCH	1600	39.8	24.5
PTCH	1000	12.7	4.0
PMCH	730	17.8	10.4
PMCP	1620	9.0	6.0

***The X/Q values are based on 2-hour average concentrations. The tracer emission rates are 2-hour averages, from the beginning of each release**

- ***X/Q from Simulation Results***

There are a number of characteristics of air quality models that influence how well simulation results represent observations. In this analysis, tracer concentrations output by the model were average concentrations for a 3-dimensional volume with a cross sectional area of 5x5 km^2 and a (surface-layer) height of 20 m (for the SCOS97 modeling domain). The observed tracer concentrations, however, represented a linear (2-hour) average at a single point. With an Eulerian model, the location of a plume of tracer concentrations can only be determined on a spatial scale commensurate with the grid resolution (5 km for this study). Also, numerical diffusion in Eulerian models tends to spread plume concentrations, thereby reducing the peak concentrations.

For this analysis, the simulated tracer concentrations used for the X/Q calculations were taken as the maximum 2-hour, onshore concentration of each tracer. The maximum simulated concentrations for each tracer ranged from 2.24 to 39.70×10^{-9} gm/m^3 (Table V-6). The maximum concentrations occurred on September 4, and represented the location at which each simulated plume reached the shoreline. Because of uncertainties in the wind fields, the time and location of maximum simulated concentrations did not exactly match those of the observations. However, for each of the 5 tracers, the county in which the simulated peak tracer concentrations occurred corresponded to that of the peak observed concentrations.

- ***Observed vs. Simulated X/Q***

In general, the simulated peak 2-hour tracer concentrations (and corresponding values of X/Q) were lower than the observed concentrations. The differences ranged from a factor of 4.4 for PDCB (e.g., 9.84 vs. 2.24×10^{-9} $hour/m^3$), to a factor of approximately 1.5 for PMCP (Table V-6). These differences were attributed to the 3-dimensional volume and the spatial scales represented by the simulation results.

To the extent that the X/Q values represented the relative onshore impact from the various tracer releases, the agreement between the X/Q values based on the observations and those based on the simulation results is less important than how well the differences among the tracer releases are represented. Relative X/Q values were calculated by dividing each of the X/Q values from the simulation results by the maximum X/Q among the 5 tracers released. For example, since the highest simulated value of X/Q was 24.5×10^{-12} $hour/m^3$ (PDCH), the resultant relative X/Q was 100%. Similar calculations were made using the observations and the resulting observed X/Q and simulated X/Qs are compared in Figure V-14.

Figure V-14
Relative X/Q for the September 4, 1997 Tracer Release

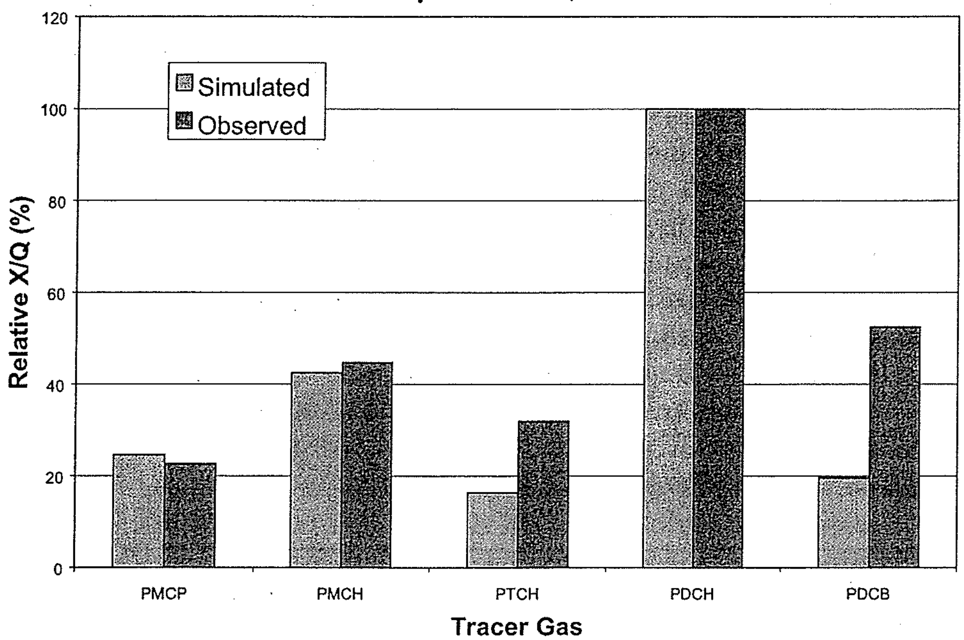


Figure V-14. shows general agreement between the relative X/Q values calculated from the observations and those calculated from the simulation results. The tracer emissions of PDCH (current lane, morning release) had the greatest relative impact in both the simulated and observed calculations. The X/Q for PTCH (proposed lane, morning release) indicates a reduced impact from PDCH of a factor of 4 based on the observed X/Q calculations and a factor of approximately 5 based on the simulated X/Q calculations. Both the observed and simulated X/Q calculations indicate a greater impact from PMCH (current lane, afternoon release) than from PMCP (proposed lane, afternoon release). The PDCB tracer represents the common point between the existing and offshore shipping lanes.

- ***Conclusions from Windfield Validation***

The comparison between observed concentrations from the tracer experiment on September 4, 1997 and simulation results using the CALMET meteorological model and the CALGRID air quality model used two analysis approaches. The first compared the relative distribution of mass from tracers released offshore through vertical planes defined from line segments representing each of Ventura, Los Angeles, Orange, and San Diego Counties. Based on this analysis, the modeling system placed 72% of the mass within the correct line segments as represented by the observation data. The second analysis approach compared observed and simulated tracer distribution ratios (X/Q). This analysis showed that the relative impact of the 5 tracer releases calculated from the simulation results were in general agreement with those calculated from the observed tracer concentrations.

C. MODELING ANALYSIS OF POTENTIAL MARINE VESSEL CONTROL STRATEGIES

As previously discussed, to mitigate the impact of emissions from offshore shipping on air quality in the SCAB, a number of marine vessel control strategies have been proposed. The proposed strategies include voluntary ship speed reductions and an alternative shipping lane. However, assessing the relative benefits of each of these strategies is difficult due to the day-to-day variations in ship traffic, changes in ship locations and emissions resulting from each of these strategies, and the complex wind flow patterns found within the California Bight. The approach used in this analysis for assessing the relative value of each strategy was to apply an Eulerian air quality modeling system to simulate the shipping lane and speed scenarios representing each of the strategies. From these modeling results, the mass of emissions from each of these scenarios impacting the SCAB was calculated. These calculations were used to assess the impact of each alternative lane and speed strategy.

SCOS97 was implemented to collect a meteorological and air quality data set suitable for modeling high ozone episodes in southern California. A field study was conducted during the period of July 15, through October 31, 1997 and included surface and aloft measurements to supplement the existing network of meteorological and air quality monitors. The result of this study was an extensive archive of aerometric data for 13 high-ozone episode days throughout the study period. As part of SCOS97, three experiments were conducted in which inert tracers were released from locations in the existing and proposed shipping lanes. Tracer concentrations were monitored along the coast of southern California from Santa Barbara County to San Diego County. The data from these tracer experiments provided a database suitable for validating a modeling system (described previously), and were subsequently used to assess the relative impacts of proposed marine vessel control scenarios.

To take advantage of the SCOS97 data sets, two episode periods from the study were selected for analysis of the alternative shipping lane and speed control scenarios. The period August 4-7, 1997 included the highest ozone concentrations observed in the SCAB during the study period. The period September 4-5, 1997 included a tracer experiment with results suitable for validating a modeling system. The validation of the modeling system was described previously. In the following analysis, emissions of nitrogen oxides (NO_x) from offshore shipping for each of the five lane and speed scenarios were simulated using an Eulerian air quality model. For each scenario, the net onshore mass flux into the SCAB was calculated. Comparisons of mass flux among the scenarios were made for each day of the two episodes simulated.

<u>Air Quality Modeling Procedures.</u>

For this analysis, the modeling system selected was comprised of the CALMET meteorological model and the CALGRID air quality model (described previously). The CALGRID simulations were begun at 0000 PDT on the day prior to the episode periods of interest. At the beginning of each simulation period, the initial concentration of NO_x

was assumed to be near zero (1.0×10^{-12} ppm) throughout the modeling domain. The extra day was needed to generate a suitable distribution of NO_x at the beginning of each episode period. Thus, the simulation periods were August 3-7, and September 3-5, 1997. The CALGRID model was run with the photochemical mechanism disabled and there were no NO_x emissions within the domain not related to offshore shipping.

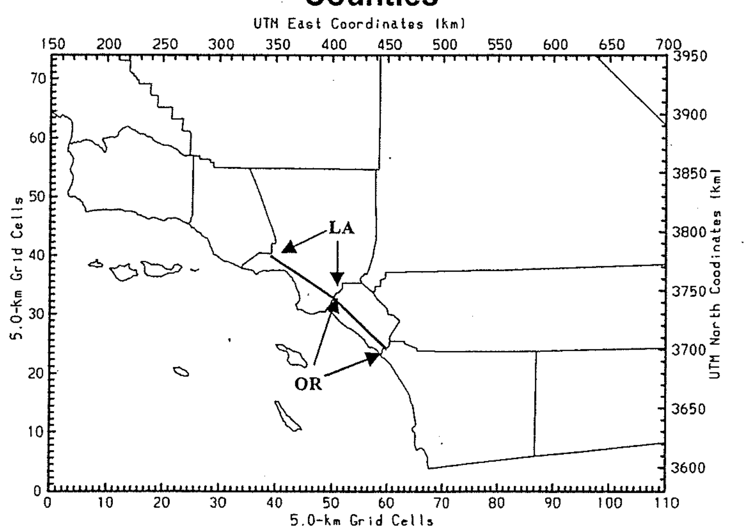
The mass flux into the SCAB for each lane and speed scenario was calculated by post-processing the CALGRID model output. Within the modeling domain, line segments were defined approximating the coastlines of Los Angeles and Orange Counties (see Figure V-15). The hourly net mass flux (HNMF, ton/hour) was calculated through the vertical planes defined by each of these line segments:

$$\text{HNMF} = (\text{CONC}) * (\text{MDEN}) * (\text{AREA}) * (\text{WSPD}) * \cos(\text{WDIR}-\text{ANGLE})$$

where CONC = NO_x concentration (ppm)
MDEN = molecular density of NO_x corrected for pressure and temperature (ton-m^{-3}/ppm)
AREA = vertical crosssectional area of each grid cell along each line segment (m^2)
WSDP = wind speed (m/hour)
WDIR = wind direction
ANGLE = orientation angle of each line segment

The daily net mass flux (DNMF, ton/day) was calculated as the accumulated sums of the HNMFs for Los Angeles and Orange Counties, for each 24-hour period beginning at midnight (0000 PDT).

Figure V-15
Southern California Ozone Study Modeling Domain Showing Line Segments Defined for Calculating Mass Flow Rates into Los Angeles (LA) and Orange (OR) Counties



Shipping Emissions Preparation

Domain-wide emissions from each of the five alternative lane and speed control scenarios were calculated for each day of the period August 3-7, 1997 (see Chapter III). The numbers of ships, ship types, ship speeds, and NO_x emission rates were determined from day-specific records of ship traffic and are described in Chapter III. For the base case (existing shipping lane), daily total NO_x emissions from ships ranged from 34.81–67.35 tons/day. The total emissions from each of the speed control scenarios were less than that those from the base case while the total emissions from the alternative lane were greater than for the base case.

Air quality models generally do not describe emissions from moving sources such as ships very well. Emission rates can only be described as hourly rates, and ship locations can only be described within the resolution of the grid cell size (5 km in this analysis). Further, the vertical distribution of emissions from ships is determined from parameters such as stack height, exhaust temperatures, and exit velocity. Air quality models are coded to calculate the plume rise from stack sources from the stack parameters. However, moving point sources with varying emission rates and stack parameters are difficult to input into the model explicitly.

The emissions from the offshore shipping scenarios were incorporated into the CALGRID model by defining a separate point source for each ship, within each grid cell of the modeling domain in which that ship was found during the August 3-7 episode period. For each hour simulated, the grid cells in which each ship spent time were identified and the point source was given an emission rate proportional to the time that the ship spent within each grid cell. The CALGRID point source input file for the base case (current shipping lane) contained 7,276 sources. The daily total NO_x emissions in the input files were calculated to verify correct emission amounts.

Shipping emissions were not prepared from observations for the September 4-5 episode. To simulate the September 3-5 period, the emission files prepared for August 3-5 were used. August 3 and 4 represent the highest daily totals of shipping emissions during the episode.

August 3-7 Simulation Results

The simulation results for the period August 3-7, 1997 show that the net mass flux ("flux") into the SCAB varied widely from day to day. For the current shipping lane, the fluxes ranged from 3.85 tons/day on August 5, to 33.3 tons/day on August 4th (Table V-8). These flux differences can be attributed to differences in daily emissions totals and differences in wind flow patterns. The flux on August 3, while not the lowest of the 5-day period, was characteristically low for each of the lane and speed scenarios and may be attributed to the low initial concentrations at the beginning of the CALGRID simulation. The results from the first day of the simulation of each episode period (August 3 and September 3) should not be considered in comparisons among the lane and speed scenarios for this reason.

Table V-8
Daily Net Mass Flux (tons/day) into the South Coast Air Basin from August 3-7, 1997 Simulation

Scenario	Aug. 3	Aug. 4	Aug. 5	Aug. 6	Aug. 7
Current shipping lane	14.27	33.3	3.85	16.44	24.96
Speed control scenario #1	13.12	31.65	3.07	14.99	23.06
Speed control scenario #2	12.18	28.92	2.68	13.66	20.49
Speed control scenario #3	13.03	30.22	3.24	14.99	22.05
Proposed shipping lane	11.15	17.45	5.67	14.62	21.87

In general, the flux into the SCAB from the current shipping lane and the speed control scenarios were correlated with the emissions totals. For example, speed control scenario #2 had the lowest average total emissions, and among those scenarios within the existing shipping lane, resulted in the lowest flux. The flux resulting from the proposed lane, however, showed a less consistent pattern compared with the other scenarios. On August 4, the flux from the proposed lane was the lowest among the scenarios with 17.45 tons/day. On August 6 and 7, the flux from the proposed lane was slightly higher. On August 5, the fluxes for all of the scenarios were relatively low (the offshore winds on this day were calm), however the flux from the proposed lane was highest among the alternatives.

<u>September 3-5 Simulation Results</u>

The simulated flux into the SCAB for September 3-5, 1997 showed characteristics that were similar to results from the August period (Table V-9). For each of the lane and speed scenarios, the flux on September 3 was much less than on September 4 and 5, suggesting the influence of the low initial conditions on the simulation results. Among the current shipping lane and speed control scenarios, the fluxes were correlated with total daily emissions. For example, speed control scenario #2 had the lowest emissions and the lowest flux among all scenarios within the current shipping lane.

Table V-9
Daily Net Mass Flux (tons/day) into the South Coast Air Basin from September 3-5, 1997 Simulation

Scenario	Sept. 3	Sept. 4	Sept. 5
Current shipping lane	10.3	31.63	22.5
Speed control scenario #1	9.64	30.27	20.45
Speed control scenario #2	9.33	28.47	18.7
Speed control scenario #3	9.57	29.7	20.28
Proposed shipping lane	7.83	14.86	35.76

The flux from the proposed shipping lane varied widely. On September 4, the flux into the SCAB was approximately 15 tons, about one-half of any of the other scenarios. However, on September 5 the flux from the proposed shipping lane was almost 36 tons, and was more than 50% greater than for any of the other scenarios.

Discussion of Simulation Results

The simulation results help to illustrate the complexity of the problem of determining the impacts of offshore emissions from shipping on onshore air quality. The wide day-to-day variations in the flux from these emissions into the SCAB for each of the lane and speed control scenarios demonstrated the importance of meteorological flow patterns in determining the flux. Changing the location of the offshore emissions through the use of an alternative shipping lane can either increase or decrease the relative impact of these emissions.

The simulation results suggest that the "carryover" of emissions from one day to the next may significantly impact onshore air quality. In both the August 3-7 and September 3-5, 1997 simulation periods, the flux on the first day was much less than for the other days (except for August 5) even though the offshore emissions on these two days were among the highest during the periods simulated (Figures V-16 and V-17). This was attributed to the low initial concentrations defined at the start of each period. However, this indicates that emissions from the previous day can be important in determining the onshore mass flux on subsequent days.

The simulation results also suggest that the benefits of relocating the emissions to an alternative shipping lane are dependent on the day-to-day variations in offshore wind flow patterns. This was most clearly illustrated in the simulation results for the September 3-5, period. On September 5, the flux from the proposed shipping lane was more than four times higher than on September 4, even though the emissions on September 5 were only about half of those on September 4. Meteorology was also an important factor in determining mass flux on August 5, when the fluxes for all scenarios were near zero.

Figure V-16
Simulated Net Mass Flux of NO_x into the SCAB from Offshore Shipping (August 3-7, 1997)

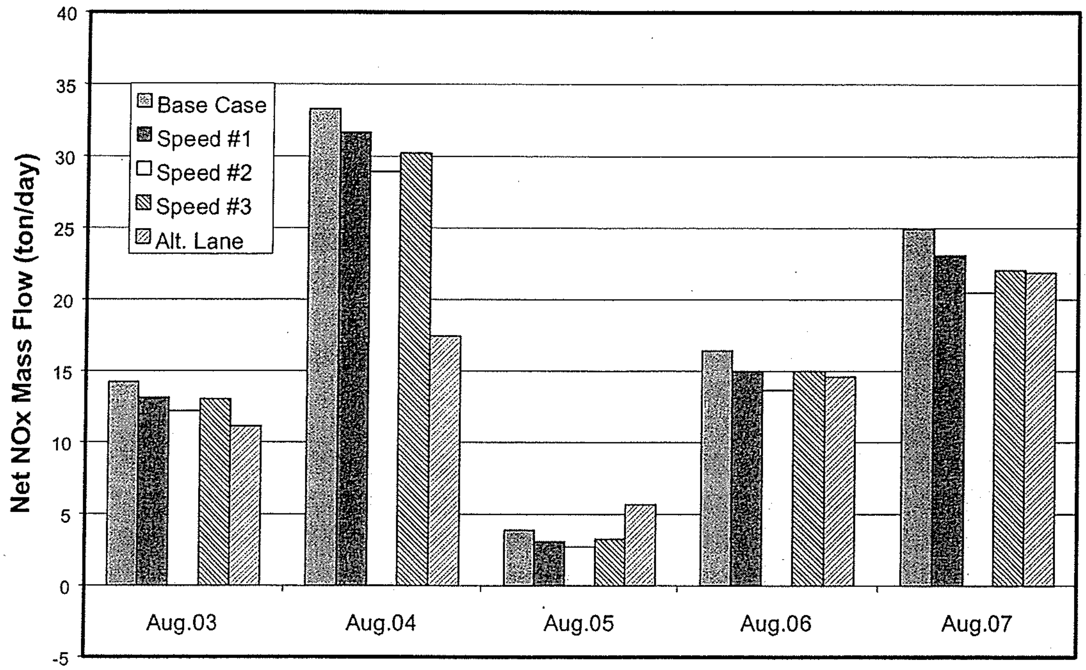
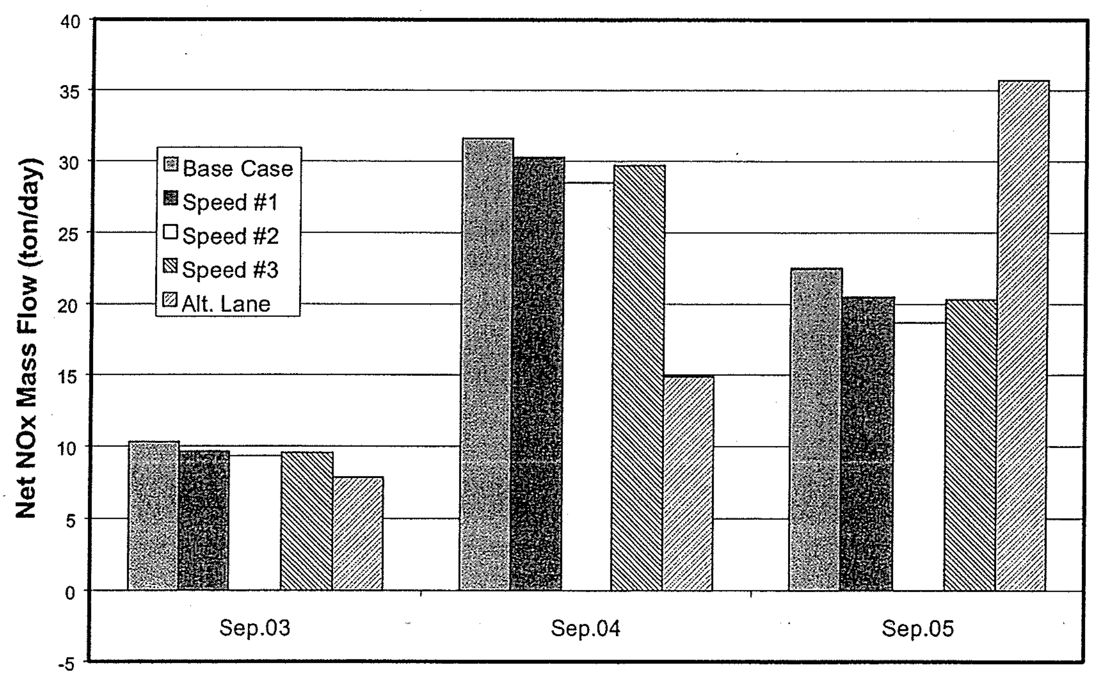


Figure V-17
Simulated Net Mass Flux of NO_x into the SCAB from Offshore Shipping (September 3-5, 1997)



Sensitivity Analyses

Sensitivity analyses are air quality model simulations in which inputs to the model are altered to assess the influence of those inputs on the output of the model. This influence is determined by comparing the simulation results with those of an unaltered, or reference, case.

Sensitivity analyses are performed for two reasons. The first reason is to determine the relative stability of the simulation results. If the simulation results vary widely in response to small changes in the model inputs, then it suggests that there is a greater uncertainty in the results. The second reason is to understand the relative importance of the various input parameters and fields. If the simulation results from the model are especially sensitive to a particular input parameter, then perhaps more care should be used in the determination of that parameter.

This section describes sensitivity analyses that were done for the August 3-7 and September 3-5, 1997 simulations of NO_x emissions from offshore shipping. For these sensitivity analyses, the reference cases were taken as the simulations done to determine the mass flow into the South Coast Air Basin (described previously). The input parameters and fields selected for alteration were those that could potentially have the greatest influence on the simulation results.

- ***Temporal Patterns in Daily Offshore Emissions–August 3-7, 1997 Episode***

As noted previously, daily totals of offshore NO_x emissions varied widely. For example, on August 4, the emissions totaled 67.35 tons and on August 5, 34.81 tons (see Chapter III). There was also a significant hourly variation in emissions within each day. For example, on August 5 the offshore emissions were approximately 4 tons/hour at 0000 PDT, but after 0200 PDT were less than 2 tons/hour (FigureV-18). On August 4, the emissions were 5 tons/hour at 0000 PDT, dropped below 2 tons/hour near mid-day, but increased to more than 3 tons/hour after 1800 PDT. Since wind flow patterns are dependent on time of day, the diurnal pattern of emissions may also influence the relative mass fluxes among the proposed shipping lane and speed control scenarios. Therefore, in this analysis, the emissions for August 4 were used for each day of the 5 day episode.

Figure V-18
Hourly NOx Emissions from Offshore Shipping–Current Shipping Lane

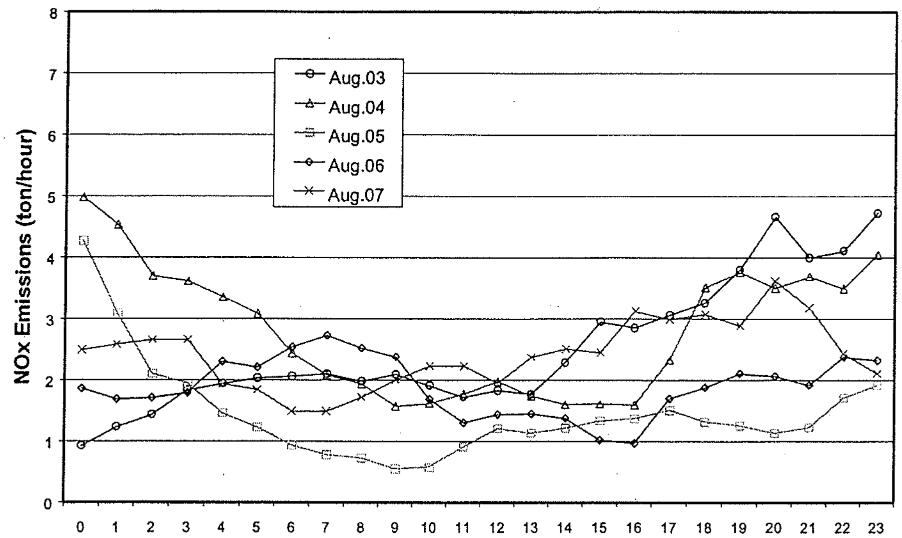
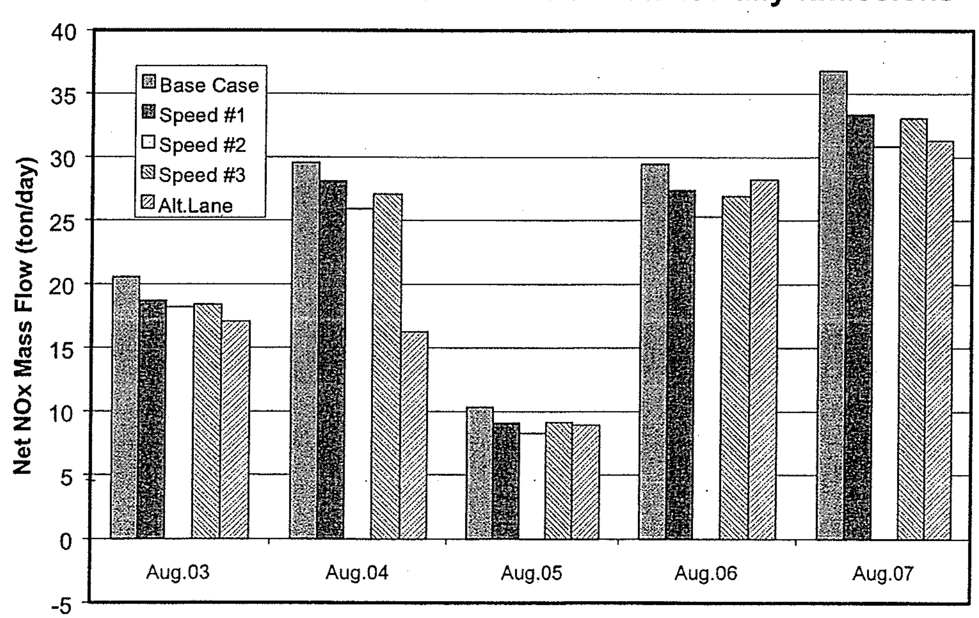


Figure V-19 shows the results of this sensitivity simulation. Comparing these results to those from the reference case (Figure V-16), it can be seen that except for August 4, the net mass flux into the SCAB was increased for each day of the simulation, for each of the alternative lane and speed scenarios. The daily emissions on August 3 were less than those on August 4; however, the emissions during the second half of August 3 were greater than for the same time period on August 4 (see Figure V-18). Thus, replacing the August 3 emissions with those from August 4 resulted in less day-to-day carryover of emissions offshore and contributed to a reduced mass flow into the SCAB on August 4.

Figure V-19
Net Mass Flux into the SCAB with Constant Daily Emissions



Compared with the reference case (Figure V-17), using the August 4 emissions for each day of the simulation changed the mass flux into the SCAB. For each of the days simulated, the current shipping lane had a greater mass flux than did the speed control scenarios. Therefore, changing the offshore emissions did not change the relative differences among these scenarios. The relative differences between the current and alternative shipping lanes did change, however. For example, in the reference case simulation for August 5, the alternative lane had a mass flow rate that was higher than for the current lane by approximately 2 tons/day. In this, analysis, the mass flow from the current lane was the higher of the two scenarios.

The results of this analysis suggest that the diurnal pattern of offshore emissions does not alter the relative mass flux rates between the base case (current shipping lane) and the speed control scenarios. The diurnal pattern of offshore emissions has a greater influence on the relative difference in onshore mass flux between the base case and the proposed shipping lane. However, the differences observed were relatively small compared with the extremes in the differences in mass flux seen on August 4.

- *Plume Rise -- September 3-5, 1997 Episode*

Within the CALGRID model, the ships represented in the analysis of offshore emissions were treated as elevated point sources. The effective plume heights (the heights at which the emissions were injected into the modeling domain) were calculated from estimates of stack heights, exhaust temperatures, and volume flow rates. For most ships, the resultant plume heights were between 150 and 325 m. However, the algorithms used to calculate these plume heights were developed for stationary point sources. The applicability of these algorithms to moving sources is unknown, however wind speed is known to reduce plume heights and moving ships would presumably have higher relative wind speeds. Also, wind speeds and directions within the California Bight are known to change with height. Therefore, exhaust plume injected at different heights may encounter different wind flow patterns. For this sensitivity analysis, the plume rise calculated within the CALGRID model was scaled (reduced) by factors of 0.5 and 0.1 to determine if the simulation results were sensitive to the plume rise algorithms (only the base case, speed control scenario #2, and the alternative lane were simulated). Figures V-20 and V-21 show the results of these sensitivity simulations.

Figure V-20
Mass Flux into the SCAB with Plume Rise Scaled by 0.1

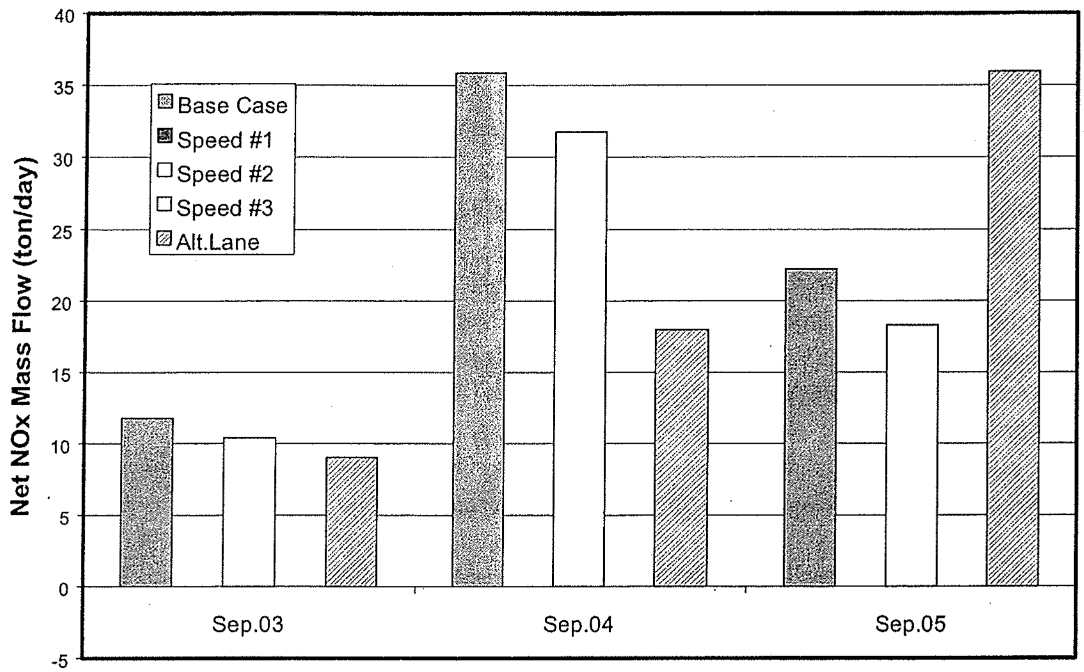
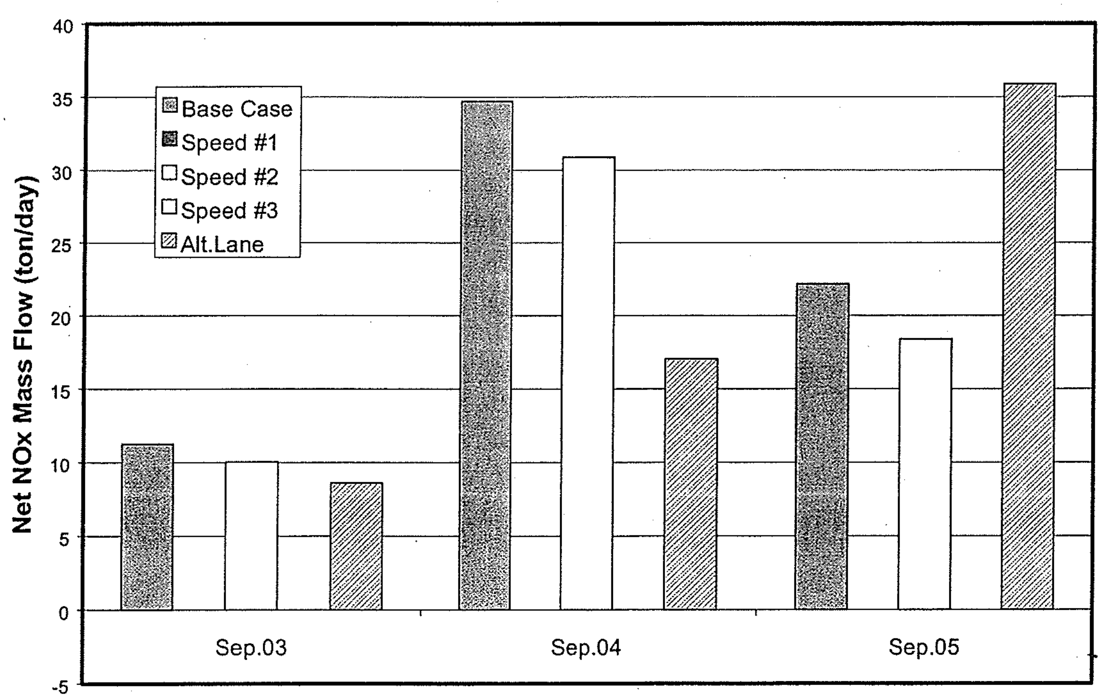


Figure V-21
Mass Flux into the SCAB with Plume Rise Scaled by 0.5



Compared with the reference case (Figure V-17), reducing the plume heights slightly increased the mass flux on September 3 and 4, but resulted in little change on September 5. For example, for the reference case, the base case scenario resulted in a mass flux into the SCAB of 32 tons on September 4. Scaling the plume rise by a factor of 0.5 resulted in a mass flow of 36 tons. However, comparing the relative differences between the base case, speed control, and alternative lane scenarios, reducing the plume height made little difference. Also, the differences in mass flux between the simulation results based on a scale factor of 0.5 and those based on a scale factor of 0.1 were small.

The results of this analysis showed that varying the effective plume heights of the offshore sources resulted in small increases in the mass flux into the SCAB. However, changes in the relative differences among the alternative lane and speed control scenarios were small.

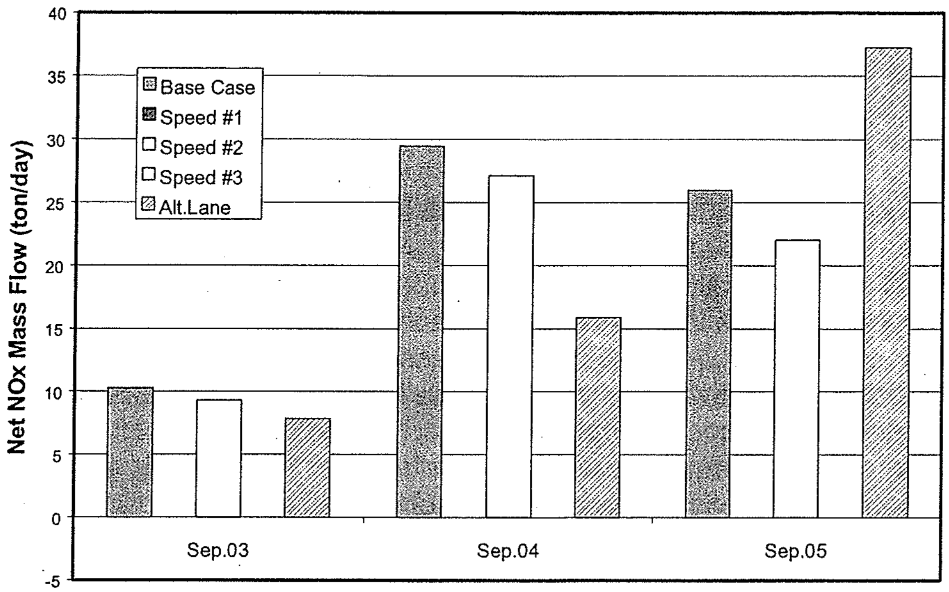
- *Wind Field Adjustment -- September 3-5, 1997 Episode*

Wind speeds and directions can change with height within the California Bight. This is often evident when comparing wind measurements at different sites on San Clemente Island. The San Clemente sites are at elevations ranging from 50 m to 550 m and wind directions can often vary by as much as 90 degrees. Ground-based measurements of vertical wind profiles (base elevation of 50 m) also show marked changes in wind directions between 50 m and 200 m.

The observed differences in wind speed and directions with height on San Clemente Island make the selection of wind observations for use in the development of the wind fields difficult. Measurements from the site at lower elevations are likely to be more representative of winds within the surface boundary layer. However, boundary-layer heights are not well known, and shipping emissions are represented in the model as elevated point sources for which winds at higher elevations may be more representative of those influencing the shipping emission release points.

In the wind field developed for the reference case, the wind measurements from the higher elevation (CLEM) on San Clemente Island were used. For this sensitivity analysis, the wind measurements from the lower elevation were used (additional measurements for Buoy 46046, located at the western end of the Santa Barbara Channel, were also included) to develop an alternative wind field. The objective of this analysis was to investigate how the changes in the resultant alternative wind field would influence the reference case simulation results (see Figure V-22).

Figure V-22
Mass Flux into the SCAB Using an Alternative Wind Field



Compared with the reference case simulation (Figure V-17), the alternative wind field resulted in only small changes in the onshore mass fluxes. For example, on September 4 the alternative wind field resulted in a mass flux from the base case scenario of 32 tons, while from the reference case it was 29 tons. The relative mass flow rates among the base case, speed control scenario #2, and the alternative lane were changed only slightly.

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